



## Preliminary insights into the fault geometries and kinematics of surface rupture along the South Leader Fault during the Mw 7.8 Kaikoura earthquake

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**Abstract:** The south Leader Fault (SLF) is a newly documented active structure that ruptured the surface during the Mw 7.8 Kaikoura earthquake. The Leader Fault is a NNE trending oblique left lateral thrust that links the predominantly right lateral 'The Humps' and Conway-Charwell faults. The present research uses LiDAR at 0.5 m resolution and field mapping to determine the factors controlling the surface geometries and kinematics of the south Leader Fault ruptures at the ground surface. The SLF zone is up to 2km wide and comprises a series of echelon NE-striking thrusts linked by near-vertical N-S striking faults. The thrusts are upthrown to the west by up to 1 m and dip 35-45°. Thrust slip surfaces are parallel with Cretaceous-Cenozoic bedding and may reflect flexural slip folding. By contrast, the northerly striking faults dip steeply (65° west- 85° east), and accommodate up to 3m of oblique left lateral displacement at the ground surface and displace Cenozoic bedding. Some of the SLF has been mapped in bedrock, although none were known to be active prior to the earthquake or have a strong topographic expression. The complexity of fault rupture and the width of the fault zone appears to reflect the occurrence of faulting and folding at the ground surface during the earthquake.

**Key words:** Kaikoura Earthquake, North Canterbury, Fault Kinematics, Fault Geometries, Transpressive Structures

### INTRODUCTION

The November 14<sup>th</sup> Mw 7.8 Kaikoura earthquake ruptured at least 14 faults of varying orientations, ages, geometries, kinematics, and total displacements (Hamling et al., 2017; Litchfield et al., 2017; unpublished data). The earthquake nucleated near the township of Waiau propagated to the northeast and produced slip on a complex network of faults in both the North Canterbury Domain (NCD) and Marlborough Fault System (MFS). The MFS and NCD are accommodating transpressive deformation in response to oblique convergence of the Pacific and Australian plates (Nicol et al., 2017). The Leader Fault, which is in the NCD, is predominantly a left-lateral oblique thrust that has a general strike of NNE and links 'The Humps' and Conway-Charwell faults. The southern part of the Leader Fault (SLF) is the focus of this study (Figure 1).

While there are other well documented transpressive structures in an overall-all strike-slip zone (i.e. California, Mongolia), the detailed geometries, surface expressions and slip within the SLF remains largely unexplained by international models. Historically, events that ruptured complex fault networks (The El Mayor Cucupah Earthquake; Gonzolez-Ortega et al. 2010; Fletcher et al., 2016) produced larger ruptures and displacements than would be expected for a single isolated fault. To improve our understanding of events that may rupture multiple faults, it is necessary to determine the main factors that influence the geometry, kinematics, and slip distribution for any given surface rupture.

The primary objective of this research at present is to analyse the slip, geometries, and kinematics of the SLF

gathered from field work offset measurements, RTK surveying and bedrock mapping) and terrestrial LiDAR at 0.5 m resolution. These data will be used to produce a kinematic model of the SLF which accounts for both the local complexities and regional tectonics. The results will be compared to and conditioned by international studies in transpressional settings.

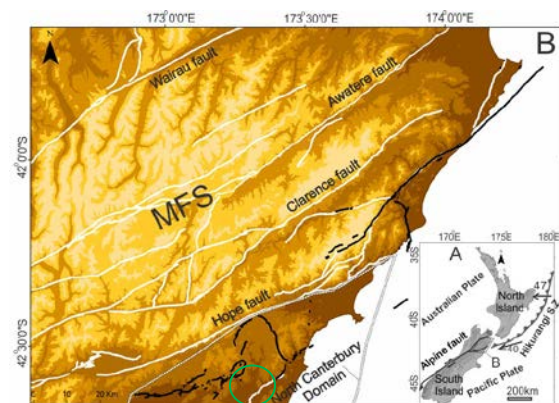


Figure 1: A) The Plate Boundary and motion vectors of New Zealand, DeMets et al., 1994. B) Digital elevation model depicting the position of the South Leader Fault (green circle) within the geological setting of the Mw 7.8 Kaikoura earthquake, where active faults are white lines and black lines are ruptures resulting from the Kaikoura Earthquake.



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Figure 2: The Waiau Wall of Woodchester: a ~3m vertical displacement (Photo by Dr. Kate Pedely)

### DISCUSSION

The Leader Fault is primarily left-lateral reverse with an overall NNE strike. The fault zone has an end-to-end strike length of ~22 km from a free tip in the south to its intersection with the Conway-Charwell Fault in the north. The SLF forms a complex zone up to ~3 km wide with strike varying through 180° and dips from 60° east to 25° west along the fault. Prior to the earthquake it had been mapped as a bedrock fault forming a Torlesse basement to Greta Siltstone Formation contact and also within the Greta Siltstone (Warren, 1993; Rattenbury et al., 2006). The fault was neither mapped in Torlesse basement nor mapped as active before the earthquake and, at the time of writing, no active fault scarps have been mapped which pre-dated the earthquake.

The SLF comprises faults striking NE and dipping at shallow angles (20–40°) to the northwest interspersed with parts of the fault that strike to the north and dip steeply (e.g., >60°; Figure 2). Shallow dipping parts of the fault have irregular rupture-trace geometries which, in part, reflect the interplay between the low fault dips and topography. These shallow faults are often located at the contact between basement and Cretaceous-Cenozoic cover rocks and/or at the base of the Greta Siltstone Formation. They appear to accommodate bedding-parallel slip, perhaps associated with flexural-slip folding of the Cretaceous-Cenozoic sequence. The steep north-striking parts of the SLF are generally contained within the Miocene Greta Siltstone Formation.

Slip on the SLF during the earthquake increased in a non-linear fashion northwards from the southern tip of the fault. Over the southern 4 km of the fault, maximum vertical and horizontal slip was 1m and 0.7m, respectively, upthrown to the west. Where strike slip is observed on these southern traces it is left lateral, although there are limited exposures where horizontal displacements can be accurately measured. To the north, the SLF is characterized by much larger displacements, where a maximum vertical and horizontal displacement are 3.4m and 2.5m, respectively. At the Waiau Wall locality (Figure 2), the faults displace the Miocene Greta Siltstone

Formation and slip is close to its maximum in the study area.

The complexity of fault rupture and the width of the fault zone was unexpected. Our ability to map this complexity has been aided by a lack of vegetation in the study area and the availability of LiDAR-derived DEM. In the absence of these data and after several hundred years of surface processes (e.g., erosion/burial) many of the surface ruptures would be undetectable. In the study area the complexity of surface ruptures appears to reflect a number of factors, including the occurrence of faulting and folding (associated with flexural slip) at the ground surface during the earthquake.

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